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Introduction

Controlled thermonuclear fusion has the potential for supplying an essentially unlimited amount of energy and is now being actively pursued throughout the world. The two primary technical approaches to fusion are: (1) magnetic confinement - where a low density plasma of hydrogen isotopes is "confined" by a magnetic field, for a period of seconds, while the plasma is heated to fusion temperatures; and (2) inertial confinement - where a solid pellet of hydrogen isotopes is compressed and heated to fusion temperatures in a time so short that fusion occurs before the material blows apart.

There are several potential devices that can be used to rapidly "heat" inertially confined fusion targets. A few of these are: ion beams, electron beams, gas lasers, and glass lasers. This paper describes the Nova glass laser fusion facility which is now in design and construction at Lawrence Livermore National Laboratory. This system, which is an extension of the currently operating Shiva laser facility(1), is designed to achieve scientific breakeven (fusion energy = laser energy) in the mid-1980's. To provide an early 1983 operational capability, with a minimum of facility down-time, the Nova laser is being constructed in two phases.

Initially a new laboratory building will be constructed adjacent to the Shiva laser to house the Phase I 10-beam Nova laser and a target chamber designed for twenty beams. The first ten beams (right side of Figure 1) will provide an 80 to 120 kJ fusion capability in early 1983. Following Phase I, the Shiva laser (shown on the left side of Figure 1) will be shut down and upgraded into ten Nova laser beams. These beams will then be combined with the Phase I beams to provide the full twenty-beam capability. The project is a congressionally funded line item and the first phase, which is presently under construction, will cost $137M. This paper will primarily describe the Phase I laser system.

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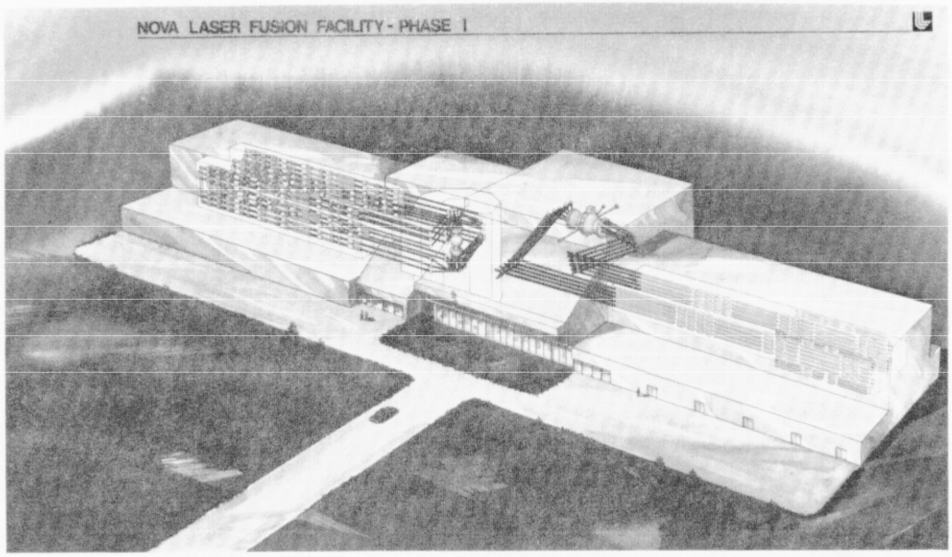

Figure 1 - Artist's concept of the Phase I Nova Laser Fusion Facility. The twenty beam Shiva laser system is shown on the left side and the new Nova laser system is shown on the right side.

Laser System

The Phase I Nova laser is neodymium-doped glass laser system, consisting of ten parallel linear laser chains, driven from a master oscillator. The Nova laser chains have been optimized to provide the maximum power and energy per dollar, and sized to stay within the technology of optical component fabrication. In addition, the laser has been configured to allow future upgrades through the addition of more amplifiers, as optical coating technology improves, and the addition of harmonic generation crystals when required by experiments.

The Nova laser chains are similar to those of the Argus and Shiva laser systems, except the Nova chains utilize laser amplifiers with diameters up to 46 cm and have 180 meters of optical propagation path. The Nova laser chains also utilize a new neodymium-doped fluorophosphate laser glass which has a nonlinear index of refraction which is approximately 35% of that of the silicate laser glass used in the Shiva system. This improved laser glass, combined with the more cost-efficient larger aperture amplifiers, allows the Nova system to achieve significantly greater performance per cost than any other glass laser systems.

The ten Nova laser chains are driven by a pulsed oscillator of appropriate pulse shape for a particular experiment. This shaped pulse is preamplified and split into the ten beams required to drive the individual laser chains. These chains consist of rod amplifiers, disk amplifiers, spatial filters, Pockels' cells, and Faraday rotator isolators. The initial stages are rod amplifiers with a 5 cm clear aperture, followed by the optical components shown schematically in Figure 2. This design consists of laser disk amplifier stages with clear apertures of 94 mm, 150 mm, 208 mm, 315 mm and 460 mm. These stages are separated by beam expanding spatial filters and contain Faraday rotator isolation stages where necessary. This chain from the 94 mm aperture through the 208 mm laser disk amplifier is similar to Shiva, except for the addition of another 150 mm amplifier and a 150 mm isolation stage, and two more 208 mm amplifiers. Following expansion to 315 mm, the laser chains are folded prior to further amplification. The 315 mm and 460 mm disk amplifiers are designed with a new rectangular pumping geometry that is more efficient and is easier to assembly. Each of these new amplifiers contains two laser disks. These 46 cm disks are split, as described later in the paper. The outputs of the final disk amplifiers are beam-expanded to 74 cm and directed, by a series of turning mirrors, to lenses mounted on the target chamber. The lenses focus the beams on the target.

This laser configuration has been selected as a result of extensive design studies and optimization efforts during the past three years. To provide the maximum output energy with a minimum probability of laser damage to optical components, a combination of coated and uncoated optics is used. The three types of optical coatings are: anti-reflection coatings, polarizer coatings, and high reflector coatings. Of these coatings, the ones currently most susceptible to laser damage are the anti-reflection coatings(2). The Nova amplifier stages (between spatial filters) have been designed so that input fluence density to the amplifiers is just below the AR coating damage level. The amplifiers then increase the fluence density to just below the uncoated damage level. The beam is then expanded to lower the fluence density to below the AR coated damage level. Thus, the input spatial filter lenses are uncoated and the output lenses are coated.

The optimum area expansion ratio is for the spatial filter determined by the equation

$$\text{area expansion ratio} = \left(\frac{\text{Bare damage level}}{\text{AR damage level}}\right)\left(\frac{\text{peak to average noise after spatial filtering}}{\text{peak to average noise before spatial filtering}}\right)$$

The peak to average noise present on the laser beam is calculated by computer modeling of the nonlinear intensification of noise sources (dirt, damage, etc.) present on the various optical surfaces both before and after filtering.

The Nova laser has been designed for "iso-fluence" (equally near the damage level at all large amplifier stages) for a pulse width of ≈ 3 ns. Figure 3 illustrates the Nova beam intensity along the laser chain for a laser output of 115 kJ at 3 ns. The solid curve represents the peak beam intensity and the points labeled M are the average beam intensities.

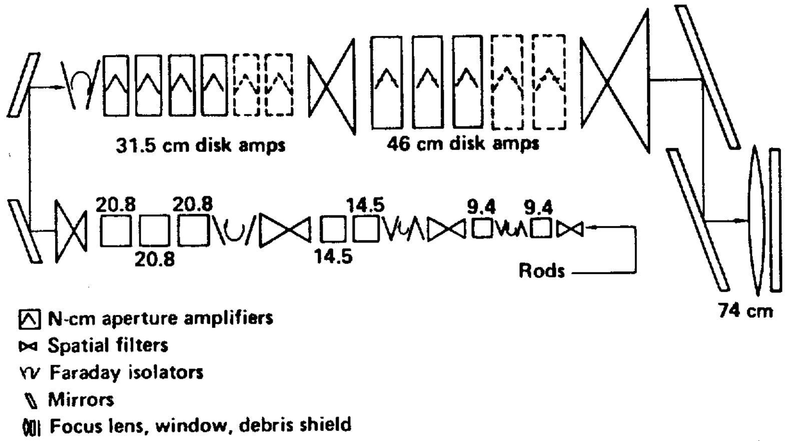

Figure 2 - Optical Schematic of a Nova Phase I Laser Chain.

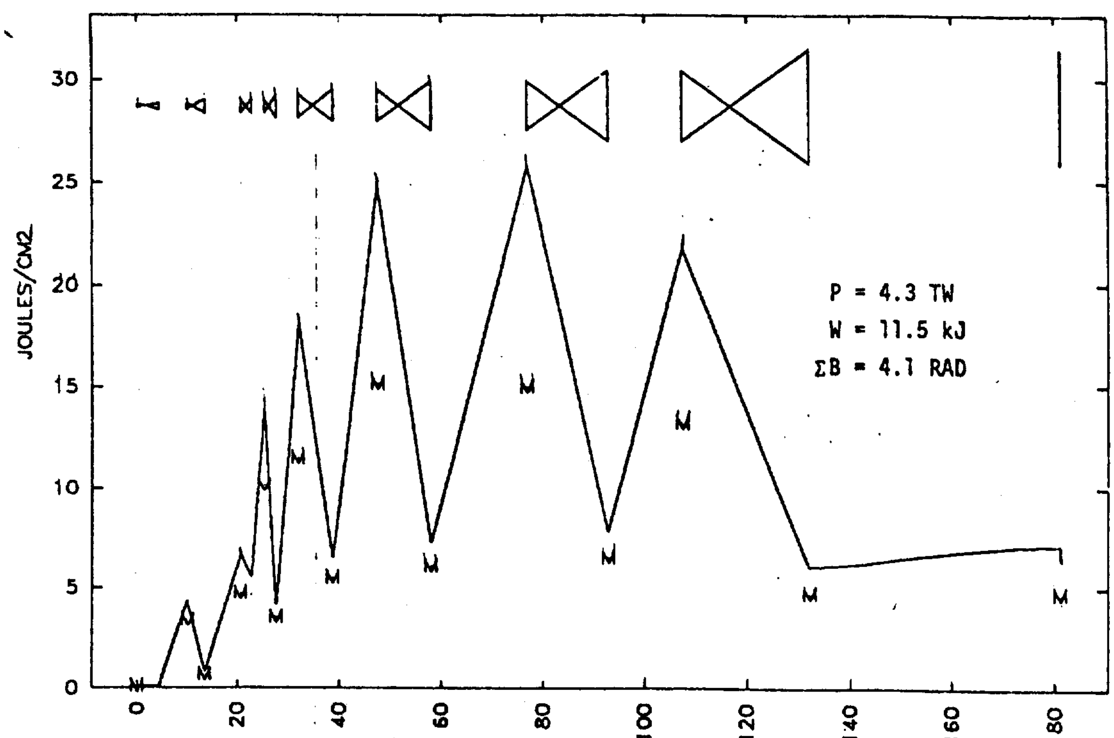

Figure 3 - Nova Phase I Beam Fluence for 3 ns Pulse.

Spatial Filters

The spatial filters between amplifier stages provide the functions of filtering, relaying, ASE reduction, and beam expanding. As a filter, they remove the high-frequency spatial noise present on the laser beam. This reduces the near-field spatial modulation peaks and allows further amplification without component damage. The spatial filter f-number and pinhole diameters are chosen to prevent closure when high energy 3 ns pulses are propagated through the spatial filters.

As an optical relay, the first spatial filter relays an image of the hard apodizer at the front of the chain to the input lens of the next spatial filter where it is re-relayed to the next filter and so on. This image relaying reduces the diffraction path length to zero and allows a nearly square spatial beam profile to be propagated through the laser chain. This provides in a high "fill factor" throughout the laser chain, which results in more efficient energy extraction. Spatial filtering and image relaying both reduce the peak to average beam intensity along the laser chain.

The spatial filters also expand the beam diameter between amplifier stages and re-collimate the beam.

Computer Control System

The Nova laser system, as with the Shiva laser system[3], utilizes a distributed multi-level computer control system. This control system architecture was selected, following a trade-off of the cost complexity and difficulty of one central computer versus a number of distributed computers.

The Nova computer control system is divided into three functional entities. One computer subsystem performs the automatic laser alignment functions for the system. The second computer subsystem performs a combination of laser diagnostics and target experiment diagnostic functions. The third computer subsystem controls the power conditioning system. All three of these subsystems are tied together into a central computer system and share a common control language.

The alignment control computer subsystem interfaces directly with the operator and interacts with a variety of micro-processors that are located adjacent to the sensors and actuators used to align the laser chains. The laser alignment functions on Nova can be broken down into the following categories: 1) oscillator alignment; 2) chain input alignment; 3) along the chain alignment system; 4) chain folding alignment system; and 5) chain output alignment system. These functions are similar to those used previously in Shiva, with the addition of the chain folding alignment system for Nova. In addition, Nova will use CCD's as video sensors and provide automatic alignment for all the above functions.

The integrated diagnostics computer control subsystem provides the diagnostic information relating to the laser system (power, energy, and pulse shape) at various points along the laser chain and handles the target diagnostic information as a result of a target experiment. To diagnose the laser system performance prior to and during a shot, there are optical sensors located along the chain at various amplifier stages. These sensors allow a determination as to the gain between stages. At the output of the laser chain is a sensor that determines the power and energy going into the target chamber. In addition, there is a sensor that determines the laser power and energy reflected from the target during a target shot. The data from these sensors are processed and recorded by the integrated diagnostics computer. Target diagnostic information is also recorded by this computer subsystem.

The power conditioning controls computer is responsible for providing all the timing and firing signals associated with the laser system and also controls the power conditioning subsystem. This subsystem provides the pulsed energy required to drive the Xenon flashlamps which pump the laser amplifiers. The 13.8 kV 60 cycle utility power is converted into 20 kV DC, which is used to charge 60 megajoules of high-energy storage capacitors. These capacitors are then switched with ignitrons to the flashlamps which excite the laser system.

New 46 cm Disk Amplifier

The 46 cm aperture disk amplifier incorporates two major innovations that improve performance. First, the amplifier uses a rectangular pumping geometry which has a higher pumping efficiency than the previous round amplifier pumping configurations.

Second, the most significant change was to split the laser disks into two half disks[2]. Normally a laser disk is a single piece of elliptically shaped glass which when mounted at Brewster's angle provides a round beam shape. The dimension of the major axis of the disk is nearly twice the beam diameter. The amplified spontaneous emission along this major axis represents a loss of pumping energy. This "de-pumping" limits the inversion or gain present in the laser disk. This loss has made large aperture amplifiers less attractive.

In order to reduce this effect, the 46 cm aperture elliptical disks are split along the short axis into two disks with edge cladding between the two halves. This reduces the maximum internal laser de-pumping length by approximately a factor of two. This means the 46 cm amplifier is much more efficient and can be pumped to nearly the same inversion value as the smaller 20.8 cm amplifier.

The beam shape is a 46 cm diameter circle with a small dark line across the middle. Ordinarily, the beam diffraction effects from this slot would cause unacceptable nonlinear laser intensifications following the amplifier. However, with apodizing, image relaying and spatial filtering, this effect is reduced to an acceptable level.

Summary

The Nova laser system, when completed, is expected to be the first inertial confinement fusion device that demonstrates scientific breakeven.

The next step would be to demonstrate the engineering feasibility of fusion by obtaining more energy from the fusion reaction than required for the laser system. To accomplish this will require even larger fusion drivers, and studies are currently underway at LLL on such systems.

Acknowledgments

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Reference

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